Engineering Science and Technology, an International Journal (JESTECH)

journal homepage: jestech.karabuk.edu.tr

Economizer design for an industrial reheating furnace

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ARTICLE INFO

Article history:
Received 22 July 2013
Accepted 07 September 2013

Keywords:
Energy,
Efficiency,
Energy balance,
Economizer,
Waste heat recovery

ABSTRACT

Depletion of energy sources, increase of energy requirement and costs, competitive conditions in the market, environmental considerations require the efficient usage of energy sources. In this study, an industrial facility rail profile mill reheating furnace flue gas waste heat recovery process was realized by an economiser in the scope of efficient usage of energy. In this respect, flue gas measurements had been done and results was evaluated, due to evaluated results and facility energy monitoring system data was used to establish mass and energy balance of the system. Economiser waste heat recovery potential, effects on the system, cost of investment and payback period of the investment had been determined. So, about 72,007,094,880 kJ waste heat energy will be saved annually by the economiser. Also, economizer efficiency determined about 84%. This energy will be used to obtain hot water and to heat offices.

1. Introduction

Energy is the essential requirement of humanity to satisfy the needs and present a comfortable life. Currently, important portion of energy need have been provided with fossil fuels which are rapidly running out. It is estimated that, reserve of fossil fuels are such that petrol and natural gas will be run out in the second half of this century. In this respect, efficient usage of energy sources is important. It is a known reality, rapid economic development of countries and global economy causes the rapid increase of energy need and consumption. Fossil fuel sources could not be available every part of the earth also economic and political conditions of the supplier regions effect the whole world. By using current technologies, Electricity production with fossil fuels causes pollution of environment. Therefore, interest on new and clean energy sources is increasing in whole world.

These days, fossil fuel energy sources consumption is rapidly increasing. Relation between energy consumption and energy sources require the efficient usage of energy. Otherwise, energy costs have been dramatically increasing. Energy saving potential is determinable as 15% industrial, 35% living quarters, 15% transportation in Turkey. These potential is higher than available energy from renewable energy sources. If steps about the efficient usage of energy be taken through the right direction, energy demand will be decreased about 20% (45 MTEP) in 2020 [1]. Iron and steel making industry is one of the most energy-intensive industries, with an annual energy consumption of about 24 EJ, 5% of the world's total energy consumption [2]. Taking into consideration the total world production of more than 1.3 billion tons of steel, the steel industry produces over two billion tons of CO_2 [3]. The International Iron and Steel Institute (IISI) in Brussels challenged governments to work with the steel industry to develop a new imaginative and global approach to climate change in the post-Kyoto period [2]. Reheating furnaces in iron and steel industry are main facilities of hot charge rolling processes. The main objective of such a reheating furnace is to control billet temperature uniformly, thereby resulting in successful rolling process performance and high productivity [4]. Furnaces, especially high temperature operation furnaces should be operated as possible as efficiently, both to decrease fuel consumption and to decrease the released greenhouse gas emissions. Wang et al. argued about the membrane based TMC technology was originally developed, demonstrated and commercialized for industrial steam boiler waste heat and water recovery. A 40% recovery of the exhaust water vapor and an increase of more than 5% in efficiency have been achieved [5]. Gewald et. al studied the possibilities of using this large amount of heat in order to increase the electricity production and efficiency of the Ano Liosia power station. Therefore, a thermodynamic and economic analysis of two different waste heat recovery (WHR) systems is conducted. The thermodynamic analysis of all WHR cycle alternatives shows that water/steam cycles generally reach a higher increase of the electrical station efficiency of up to 37%, compared to ORC alternatives [6]. Economiser is heat recovery equipment which is mounted on the flue gas line of the combustion systems. Economiser is a simple gas to fluid heat exchanger and

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used to exchange the heat from hot flue gas stream to circulation water. Obtained hot circulation water could be obtained to heat the heating system circulation fluid or to heat hot usage water. Economisers have different configurations as straight tube, U tube, finned tube, helical tube, fire tube. Economiser design and manufacturing require the consideration of parameters is operation pressure, fuel type, gas residue, process requirements, and layout plan. These parameters require different tube material and manufacturing style as welded or seamless tube, stainless tube, straight tube, u tube, helical tube or finned tube. Economiser is used to recover waste flue gas heat and obtain hot usage or heating water in industrial facilities. So, fossil fuel combustion for heating or to obtain hot usage water is eliminated and also by the heat recovery. Heat recovery means lower energy source consumption to obtain energy and lower carbon emission. Technical drawing of the system economiser appliance discussed in this paper was presented in Figure 1.

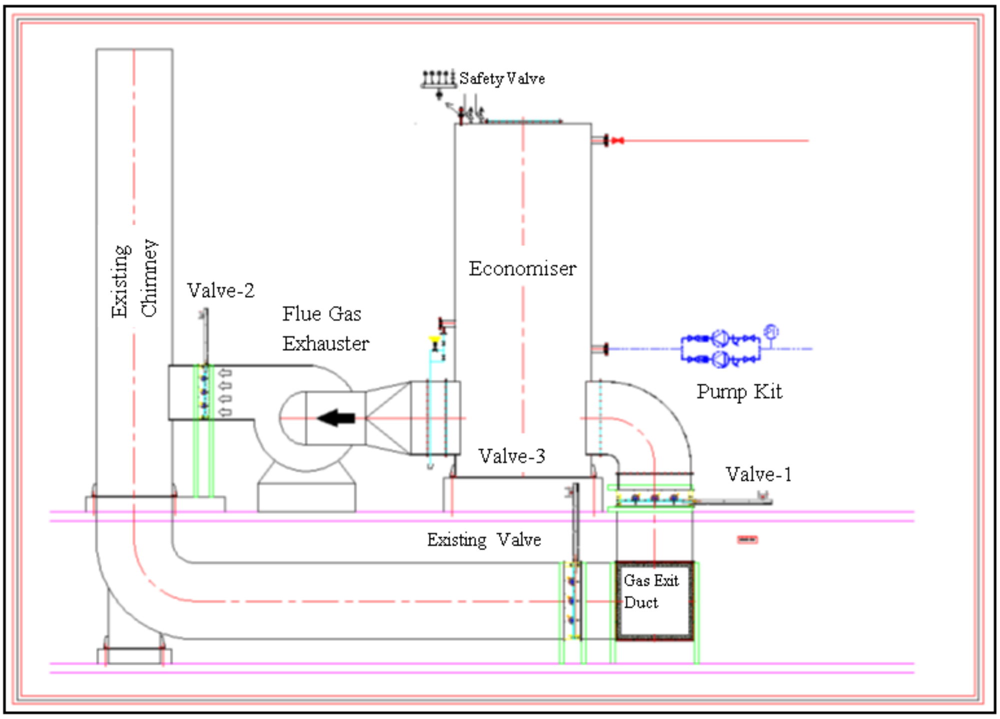

Figure 1. Schematic layout of economiser establishment.

Figure 2 shows the applied system economiser application picture.

Figure 2. Economiser assembly picture.

In this study, an industrial facility rail profile mill reheating furnace economizer appliance and waste heat recovery was aimed. In this respect, on site measurements from the system and online data from the control system was taken. System energy and mass balance was established. Waste heat recovery potential was determined. Simple investment and payback period was shown. Then the investment and establishment successfully completed. Lastly, system assessed and displayed destination is reached.

2. Material and Method

2.1. Energy Balance and Saving

In order to understand the importance of economizer appliance of an industrial furnace, the waste flue gas and recovery potential should be analysed. Within this study period on site temperature, pressure and flue gas chemical content measurements gave opportunity to establish mass and energy balance analysis. System waste heat potential was determined and possible recovery equipment the system was recommended to the decision makers of facility. Facility has baths and to heat facility work space, offices coal had been using. By the appliance of this study, obtained hot water was used instead of coal boilers. So, while waste heat recovery was providing, carbon emission decreased and fossil fuel consumption was eliminated.

Flue gas heat potential was estimated with:

$$Q_{bg} = \dot{m}_{bg} \, c_{p_{bg}} \Delta T_{bg} \tag{1}$$

$\dot{m}_{bg}$ mass flow rate of flue gas, $c_{p_{bg}}$ specific heat of flue gas, ΔT_{bg} flue gas inlet and exit temperature difference. Coke oven gas and blast furnace gas was using as fuel in real profile reheating furnace. Flow rates of these gases were given in Table 1.

Table 1. Reheating furnace fuel flow rates.

Coke oven gas (Nm^3/s)	4,637
Blast furnace gas (Nm^3/s)	580

Chemical contents of blast furnace gas and coke oven gas were given in Table 2 and Table 3.

Table 2. Chemical content of coke oven gas [7].

Coke Oven Gas Chemical Content (Mass base, %)	
CO_2	3.01
C_2H_4	1.62
O_2	0.37
CO	6.68
H_2	57.75
CH_4	22.28
C_2H_6	0.62
C_2H_2	0.11
N_2	6.87
Inert	0.69
LHV (kJ/kg)	16,747.2
HHV (kJ/kg)	18,928.52

Table 3. Blast furnace gas chemical content [7].

Blast Furnace Gas Chemical Content (mass base %)	
CO_2	18.64
CO	23.17
H_2	2.08
N_2	56.11
LHV (kJ/kg)	3,152.66
HHV (kJ/kg)	3,194.52

Rail profile mill reheating furnace combustion theoretical analysis was given in Table 4 and Table 5.

Table 4. Combustion chemical analyses of rail profile mill reheating furnace coke oven gas [7].

Coke oven gas			**Combustion products (Nm^3/h)**							
Fuel Analyses	**% (ob)**	**Stok. O_2**	**CO_2**	**SO_2**	**N_2**	**Argon**	**H_2O**	**O_2**	**Inert**	**Diğer**
CO_2	3.01	0.00	139.57	0.00	0.00	0.00	0,00	0.00	0.00	0.00
C_2H_4	1.62	225.36	150.56	0.00	839.90	10.00	169,96	0.00	0.00	0.11
O_2	0.37	-17.16	0.00	0.00	-63.94	-0.76	-0,76	0.00	0.00	-0.01
CO	6.68	154.88	309.97	0.00	577.22	6.88	13,55	0.00	0.00	0.07
H_2	57.75	1,338.93	1.92	0.00	4,990.16	59.44	2795,02	0.00	0.00	0.64
CH_4	22.28	2,066.25	1,036.08	0.00	7,700.84	91.72	2247,03	0.00	0.00	0.99
C_2H_6	0.62	100.62	57.64	0.00	375.02	4.47	95,05	0.00	0.00	0.05
C_2H_2	0.11	12.75	10.22	0.00	47.53	0.57	6,22	0.00	0.00	0.01
N_2	6.87	0.00	0.00	0.00	318.56	0.00	0,00	0.00	0.00	0.00
Inert	0.69	0.00	0.00	0.00	0.00	0.00	0,00	0.00	32.00	0.00
Total	**100**	**3,881.63**	**1,705.97**	**0.00**	**14,785.3**	**172.31**	**5326,06**	**0.00**	**32.00**	**1.85**
Excess Air			2.83	0.00	7,368.62	87.77	172,98	1,977.11	0.00	0.94
Exhaust Gas Composition % (ob):			**5.40**	**0.00**	**70.03**	**0.82**	**17.38**	**6.25**	**0.10**	**0.01**

Table 5. Rail profile mill reheating furnace blast furnace gas and combustion products chemical content [7].

Blast furnace gas			**Combustion products (Nm^3/h)**						
Fuel Analyses	**% (ob)**	**Stok. O_2**	**CO_2**	**SO_2**	**N_2**	**Argon**	**H_2O**	**O_2**	**Diğer**
CO_2	18.64	0.00	108.11	0.00	0.00	0.00	0.00	0.00	0.00
CO	23.17	67.19	134.48	0.00	250.43	2.98	5.88	0.00	0.03
H_2	2.08	6.03	0.01	0.00	22.48	0.27	12.59	0.00	0.00
N_2	56.11	0.00	0.00	0.00	325.44	0.00	0.00	0.00	0.00
Total	**100**	**73.23**	**242.60**	**0.00**	**598.35**	**3.25**	**18.47**	**0.00**	**0.03**
Excess Air			0.11	0.00	288.64	3.44	6.78	77.45	0.04
Exhaust Gas Composition % (ob):			**19.59**	**0.00**	**71.58**	**0.54**	**2.04**	**6.25**	**0.01**

By using data from Table 4 and Table 5, reheating furnace combustion theoretical exhaust gas, theoretical combustion air, excess air, total theoretical exhaust gas, excess air coefficient was evaluated and given in Table 6.

Table 6. Theoretical gas flow rates [7].

Theoretical Exhaust Gas (Nm^3/h) (ob)	22,886
Theoretical Combustion Air (Nm^3/h) (ob)	19,224
Excess Air (Nm^3/h)	9,987
Theoretical Total Exhaust Gas (Nm^3/h) (ob)	32,873
Furnace Air Inlet (Nm^3/h)	29,210
Excess Air Rate (%)	51.95

According to the estimated and measured data mass and energy balance was established and results were given in Table 7.

Table 7. Total energy balance of reheating furnace.

SYSTEM TOTAL ENERGY BALANCE						
Inlet	**Flow Rate (Nm^3/h)**	**Oxygen (%)**	**Temperature (°C)**	**c_p (kJ/Nm^3K)**	**Q (kW)**	**%**
Blast Furnace Gas (Combustion Heat)	580			3.152.66	507.92	2,22
Blast Furnace Gas (Sensible Heat)	580		35	1.37	7.76	0,03
Coke Gas (Combustion Heat)	4637			16,747.2	2,157.13	94,29
Coke Gas (Sensible Heat)	4637		25	1.35	43.68	0,19
Combustion Air (Sensible Heat)	29210	20,57	20	1.35	210.76	0,92
Cooling Water	503*		24	4.18 **	14.04	0,06
Bloom	70846*		55	0.44**	476.73	2,08
Total					**2,614.54**	**100,00**
Exit	**Flow Rate (Nm3/h)**	**Oxygen (%)**	**Temperature (°C)**	**c_p (kJ/Nm^3K)**	**Q (kW)**	**%**
Flue Gas	32873		593	1.57	8,501.65	32,52
Bloom	69571*		1,077	0.68**	1,416.04	54,16
Cooling Water	503*		29.00	4.18**	16.96	0,07
Scale Loses (%1,8 assumed)	1275,23*		1,077	0.68**	259.56	1,13
Other loses (Openness, wall loses, etc.)					3,247.60	14,20
Total					**2,614.54**	**100,00**

*kg/h, **kJ/kg°C

2.2. Saving Potential of Economizer Application

Energy saving potential of economizer application to the reheating furnace was determined and given in Table 8.

Table 8. Energy saving potential of economizer.

Flue Gas Flow Rate (Nm^3/h)	30,000
Economizer Flue Gas Inlet Temperature (°C)	350
Economizer Flue Gas Exhaust Temperature (°C)	150
C_p (kJ/Nm^3K)	1.37
Energy Saving (kW)	2,283.33
Annual Operation Time (h)	8760
Annual Energy Saving (kJ)	72,007,094,880

2.3. Heat Recovery Potential of Economiser

Annual energy saving potential is 72,007,094,880 kJ and higher heating value (HHV) of coal is 24,480.21 kJ/kg. Cost of 1 kg coal is 0.23 € . Saving energy potential equality is about 2,941,441 kg/year. Economical size of this potential is equal to 676,531 €.

2.4. Economizer Labour Force Saving

Coal preparation and boiler coal firing operators was 2 worker for 3 shifts. 6 worker annual labour cost was about 125,000 €. This labour force is using for other works of facility and this cost was eliminated. Possible work accidents as burning and smoke poisons were eliminated and so pecuniary and spiritual gaining was obtained.

2.5. Economiser Electricity Consumption Cost

Fan motors operate about 8,760 hours annually. A motor consumes about 37 kW. Annually about 324,120 kWh energy is consumed by fan motors. 1 kWh electricity is about 0.08 € and so annually about 25,930 € electricity cost is payable. 2 unit circulation pumps consume 5 kW and annually about 43,800 kWh energy is consumed. Pumps energy consumption cost is about 3,504 €. Total cost of electricity is estimated as 29,434 €/year.

2.6. Economizer Investment Cost

Economizer investment cost was 190,000 €.

2.7. Payback Period

Total owning cost occurs from electricity and investment costs. The total cost of the appliance is about 219,434 € for this project. Saving is determined as fuel and labour cost and is about 804,989 €. Simple payback period determined as about 3.6 month. Financial analysis and simple payback period was given in Table 9.

Table 9. Cost, saving and payback period of the appliance.

	Cost (€/year)	Saving (€/year)	Payback period (month)
Economiser	190,000	801,531	---------
Electricity	29,434	---------	---------
TOTAL	219,434	801,531	3.6

3. Results and Discussion

Industrial facility reheating mill furnace waste heat energy was recovered by the appliance of an economiser. Measurements and facility energy management system data was used to establish the mass and energy balance. A recovery potential and simple payback period was determined. By the usage of economiser, energy saving from the facility energy sources as electricity, coal was obtained. About 190,000 € was invested to the economiser. Obtained hot water by economiser for heating or usage had been require the combustion of coal which costs annually about 679,989 € before. Simple payback period of the investment was estimated as 3.6 month.

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